Development of a Regional Coastal and Open Ocean Forecast System

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LONG-TERM GOALS

The long term goal is to construct, verify and demonstrate an efficient system for the realistic, accurate and efficient estimation of oceanic fields which can be deployed rapidly in any region of the world ocean: the coastal and shelf ocean, across the shelfbreak and the open ocean.

OBJECTIVES

The objectives of this research are:

i) to continue the development of a relocatable, portable and efficient ocean prediction system for real time forecasting and interdisciplinary research;

ii) to demonstrate and validate the Harvard Ocean Prediction System (HOPS) in real time exercises at sea and on land;

iii) to implement regional forecast system methodologies; and

iv) to share software with the modeling and operational community

APPROACH

Work is ongoing in the areas of:

i) real time operational methods and protocols;

ii) advanced techniques for efficient regional prediction, predictability and validation; and

iii) extension and refinements of software

In carrying out continuing research in the three phases (Exploratory, Dynamical, Predictive) of regional forecast system development and the real time forecast process, particular emphasis is now placed on error models, forecasts of error, automated adaptive sampling and automated evaluation of quantitative skill metrics. The approach to software implementation allows for simple and flexible inter-module flow of information and the addition of modules, models and procedures developed in-house or elsewhere. Standard data management procedures, data formats, generic data assimilation schemes amenable for use in diverse models are required. The approach to data assimilation

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14. ABSTRACT
The long term goal is to construct, verify and demonstrate an efficient system for the realistic, accurate and efficient estimation of oceanic fields which can be deployed rapidly in any region of the world ocean: the coastal and shelf ocean, across the shelfbreak and the open ocean.

15. SUBJECT TERMS

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emphasizes treatment of the data before assimilation via Structured Data Models (e.g. feature models and Empirical Orthogonal Functions - EOFs) which are used to represent synoptic structures.

WORK COMPLETED

HOPS was applied in a distributed real time operational manner for two major exercises in the past year: Generic Oceanographic Array Technology System/Multi-Scale Environmental Assessment Network Studies (GOATS/MEANS 2000) and Assessment of Coastal Ocean Transients (ASCOT-01). GOATS/MEANS 2000 took place in September-October 2000 in the area of the island of Elba, off the western coast of Italy [8]. During this exercise, HOPS was used to: demonstrate the ability to operate HOPS from Harvard in real time with data collected over 6000km away; issue 11 sets of forecasts for two nested forecast domains via the Internet; demonstrate inter-model nesting with CU-POM; provide daily adaptive sampling tracks for research vessels and Autonomous Underwater Vehicles (AUVs); demonstrate nested modeling for forecasting in shallow waters; and, investigate the effects of regional dynamics on local conditions. Results of the HOPS modeling effort can be found on-line at: http://www.deas.harvard.edu/~robinson/GOATS/index.html.

ASCOT-01 was a coupled multi-scale interdisciplinary forecast experiment carried out in Massachusetts Bay and the Gulf of Maine in June 2001 by Harvard University and the NATO Undersea Research Centre (SACLANTCEN). The objectives of ASCOT-01 were to: 1) carry out and quantitatively evaluate in Massachusetts Bay (MB) and the Gulf of Maine (GOM) a coupled multiscale interdisciplinary real time forecast experiment; 2) obtain an intensive data set adequate for definitive quantitative skill assessment and suitable for the design of minimal data requirements for both REA and for an efficient regional monitoring and prediction system; 3) obtain a data set: adequate to define multiscale physical dynamical processes (sub-meso-, meso-, bay-, gulf- scales) that govern the formation and evolution of structures and events, including generic processes and the coupling of wind-forced events and buoyancy currents; and capable of providing a context for interdisciplinary forecasting and process studies; and 4) maintain, via surveys and adaptive sampling, a continuous synoptic description of Massachusetts Bay with mesoscale resolution throughout and sub-mesoscale resolution as dynamically required. The ASCOT project is a series of real time Coastal Predictive Skill Experiment/Rapid Environmental Assessment (CPSE/REA) experiments and simulations focused on quantitative skill evaluation and cost-effect forecast system development. ASCOT-01 forecast products were generated in a distributed fashion, with hydrographic analyses carried about aboard the NRV Alliance, while biological analyses and forecasts were carried out at Harvard University. During the period 9-25 June 2001, 31 sets of forecast products for Massachusetts Bay and the Gulf of Maine were issued, utilizing over 600 CTD casts collected during the exercise. Adaptive sampling tracks for the NRV Alliance and two coastal vessels from the Dartmouth and Boston campuses of the University of Massachusetts were designed aboard the NRV Alliance. ASCOT-01 background information and forecasts products are on-line at: http://www.deas.harvard.edu/~leslie/ASCOT01/index.html.

The development of real time, advanced, generic, portable, multiscale, interdisciplinary Ocean Observing and Prediction Systems is ongoing and is documented in [1,3,8]. Important issues in interdisciplinary (coupled biological-physical) data assimilation are addressed in [6,7]. The features of dominant mesoscale variability, circulation patterns and main dynamics occurring in the Strait of Sicily were studied and classified [2].

Multiple 2-way nested Northwest Atlantic domain configurations have been established for a variety of applications. The progress of the development of the Advanced Fisheries Management Information System (AFMIS) is presented in [4]. Circulation feature models [9,10] in a general form and specifically for the Gulf of Maine have been developed.

The Error Subspace Statistical Estimation (ESSE) approach was extended to physical-biological and physical-acoustical fields. The ESSE codes (error forecast, melding or Kalman update, etc) were extended to physical-biological fields. Software was written for biological measurement models so as to link the biological model state variables to the biological data. Initialization procedures and software were also improved and further developed. These new methodologies and software were utilized in real time during the ASCOT-01 experiment to carry out coupled data assimilative forecasts of physical-biological fields in Massachusetts Bay.

The transfer of environmental uncertainties to acoustic fields was carried out via ESSE for the PRIMER region [5] and the coupled assimilation of physical and acoustical data is underway. Simple stochastic models of internal tides were added to HOPS, complementing our stochastic model for the effect of sub-grid-scale eddies. Software for the analysis of error Probability Density Functions (PDFs) were developed.

The developments implemented and released under the direction of Dr. Patrick J. Haley, Jr., project lead scientist, in HOPS software in the past year have been primarily directed to improving our 2-way nesting capabilities. Tools to ensure consistency in topography between nested domains have been released. Improvements to the tools to construct consistent initializations between nested simulations have been disseminated. Improved timing probes have been introduced and used to improve efficiency in our nesting implementation. The nesting has been tested in a 2-domain configuration in GOATS/MEANS 2000 and in a 3-domain configuration in ASCOT-01. The free surface code previously reported as implemented has undergone significant testing and is essentially now a part of the operational software.

RESULTS

The Harvard Ocean Predictions Systems was put to use during the past year in two major exercises. These took place in the regions off Elba, Italy and in Massachusetts Bay/Gulf of Maine. The unique requirements of each of these operational exercises necessitated software development, from which a new generation of HOPS has been created. Considerations included: a domain in which there was considerable variation in bottom depth (both very shallow and very deep) as well as islands; and, how to use sigma and hybrid vertical coordinates schemes to maintain required vertical accuracy and yet to develop and use intuitive and practical real time quantitative skill metrics. In each exercise, data collected was used for the first time in an operational exercise in a dual fashion: first as validation of forecast results and second as assimilation data for ongoing forecasts.

The use of error subspace allows for an accurate, global, multi-scale and multi-variate, three-dimensional analysis of primitive equation fields and their errors in real time [1], as demonstrated for the Middle Atlantic Bight and the eastern Mediterranean. Rapid Environmental Assessment (REA) Ocean Observing and Prediction Systems require portability, flexibility, rapid relocateability, inclusivity with respect to coastal processes and scalability with respect to hardware and software [3].

The development of a multi-disciplinary ocean forecast system and its application in a real time demonstration of concept has been demonstrated [4]. Feature-oriented regional modeling for various types of fronts is presented in a generalized approach in [10]. Large-scale meandering frontal systems such as the Gulf Stream, Kuroshio, etc. can be modeled via velocity-based feature models. Buoyancy forced coastal water mass fronts such as coastal currents, tidal fronts, inflow/outflow fronts, etc. can be modeled by a generalized parameterized water mass feature model. The multi-scale synoptic circulation systems in the Gulf of Maine and Georges Bank region are summarized using a feature-oriented approach in [9]. A synoptic initialization scheme for feature-oriented regional modeling and simulation of the buoyancy-driven circulation in the coastal-to-deep region has been developed. The applicability of feature-oriented regional modeling and simulation for multi-scale, multi-domain, multi-platform and multi-disciplinary nested forecast systems has been demonstrated.

The modern methodology of relating natural data and dynamical model to provide estimates of nature which are better estimates than can be achieved by using only the observational data or the dynamical model has been described in [6]. This document introduces concepts, describes purposes, presents applications to regional dynamics and forecasting, overviews formalisms and methods and provides and selected range of examples. The extension of this methodology to highly non-linear coupled biological-physical dynamics is documented in [7] through a series of detailed case studies. Combining hydrographic data with HOPS by data assimilation, the main features of dominant mesoscale to sub-basin-scale variability in the Strait of Sicily during the summer of 1996 have been estimated and revealed, and several of their dynamical properties described [2]. The dominant dynamical variations were revealed to be linked to the Atlantic Ionian Stream and associated with five features: the Adventure Bank Vortex, Maltese Channel Crest, Ionian Shelfbreak Vortex, Messina Rise Vortex, and temperature and salinity fronts of the Ionian slope.

The uncertainties in the predicted acoustic wavefield associated with the transmission of low-frequency sound from the continental slope, through the shelfbreak front, onto the continental shelf have been examined in [5]. The combined ocean and acoustic results from the simulation study provides insights into the relations between the uncertainties in the ocean and acoustic estimates.

Important upcoming operational plans are for ASCOT-02, an additional study of forecast skill to take place in the area of Elba in May 2002. The GOATS/Means 2000 experiment comprised the Exploratory and Dynamical phases of the development of a forecast system for the Elba region. ASCOT-02 will conclude the Dynamical phase and will begin the Predictive phase.

Additional information on the work accomplished for this project is available via the principal investigator's web site: http://www.deas.harvard.edu/~robinson .

IMPACT/APPLICATIONS

Ocean Observing and Prediction Systems for contemporary ocean science and marine technology consist generally of: i) a set of coupled interdisciplinary models; ii) an observational network with multiple platforms and sensors; and, iii) data assimilation schemes with measurement models and error models. The nowcasts, forecasts and data driven simulation products of Ocean Observing and Prediction Systems have important applications for: i) the efficient conduct of real time scientific research in the intermittent ocean; ii) marine resource exploration, exploitation and management; and, iii) naval and marine operations.

The Portuguese Hydrographic Institute has utilized HOPS to provide forecasts of oceanic evolution during naval operations (LinkedSeas 2000 and SwordFish 2001) in both deep and coastal areas for support of anti-submarine warfare (ASW) operations. Their comparisons of operational results when HOPS was used as compared to when it was not used indicated a significant improvement in successful ASW operations when HOPS was employed.

TRANSITIONS

Completed and continuing research transitions and collaborations are with: MIT Sea Grant; Southampton Oceanography Center; NRL Stennis; Naval Postgraduate School; SACLANT Undersea Research Centre; WHOI; SIO; Univ. of Colorado; JPL Pasadena; Old Dominion University; Institute of Marine Sciences, Turkey; U. Tokyo; CNR Ancona, Italy; U.Cal. - Santa Cruz; and U. Mass. Dartmouth, School for Marine Science and Technology. The ESSE methodologies and codes continue to be transferred to ROMS-TOMS in collaboration with Rutgers Univ. Work continues with UMass-Dartmouth in the transition of HOPS to a Regional Fisheries Application Center (RFAC).

RELATED PROJECTS

The collaborations with the SACLANT Undersea Research Centre's Oceanography Group are evidenced by the recent exercises GOATS/MEANS 2000 and ASCOT-01, and the upcoming ASCOT-02 exercise. This project has relationships with: Harvard 6.1 research (“Dynamics of Oceanic Motions”); Harvard Uncertainty research ("Uncertainties and Interdisciplinary Transfers Through the End-to-End System (UNITES): Capturing Uncertainty in the Common Tactical Environmental Picture"), as well as external collaborations in conjunction with transitions.

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